

Science & Technology REVIEW

June 1998

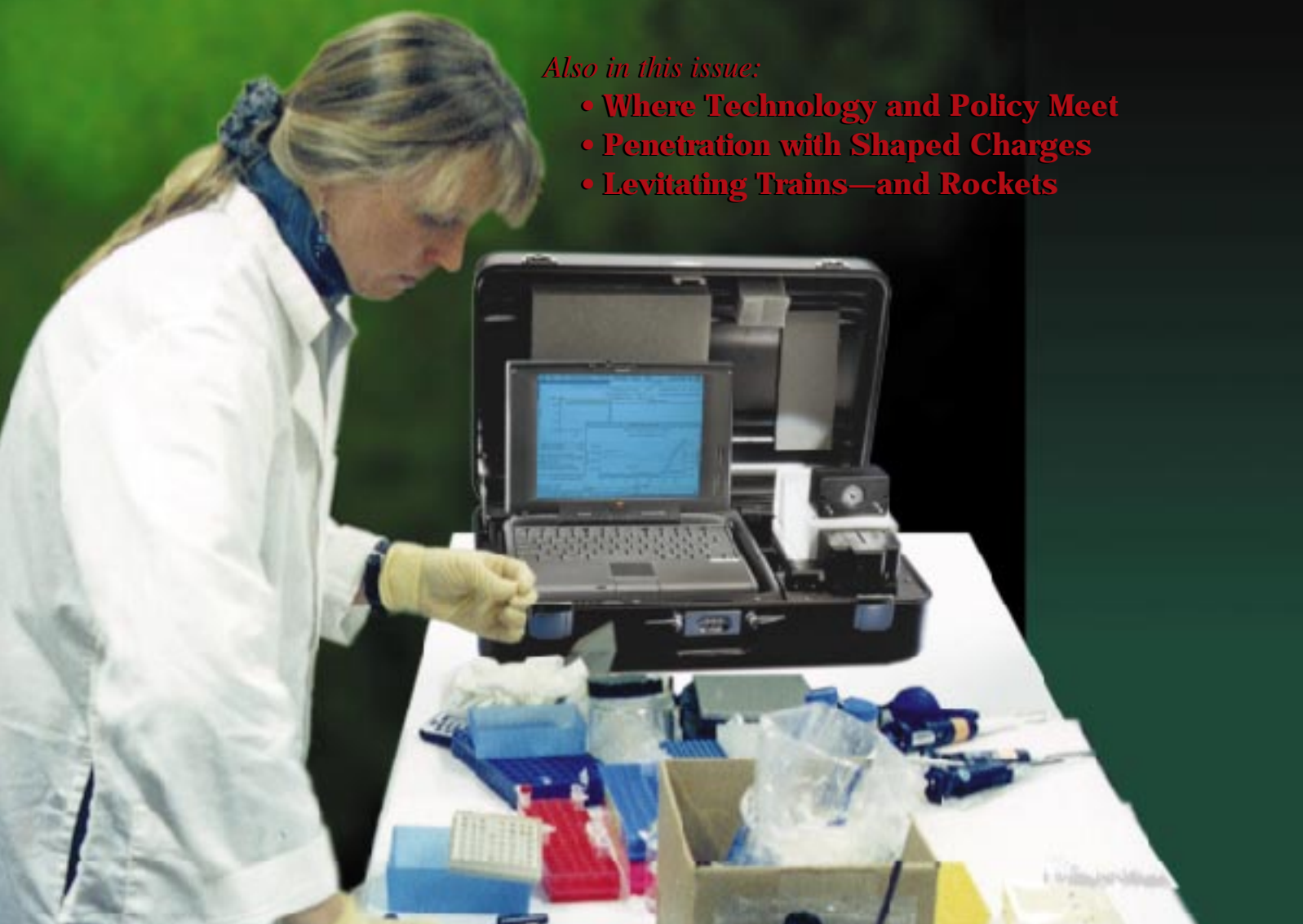
Lawrence
Livermore
National
Laboratory



Countering the Bioweapons Threat

Also in this issue:

- **Where Technology and Policy Meet**
- **Penetration with Shaped Charges**
- **Levitating Trains—and Rockets**



About the Cover

An important part of the Laboratory's commitment to national security is the development of technologies to counter the threat of biological weapons. The article beginning on p. 4 reports on Lawrence Livermore's multidisciplinary work to protect the nation from bioweapons attack. Pictured on the cover is scientist Phoebe Landre preparing samples of nonvirulent bacterial simulants used to test detectors such as Livermore's portable single-chamber polymerase chain reaction unit shown here. In the background, magnified many thousand times, is an image of a nonvirulent bacterial simulant used in field-trial tests of these detectors.



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About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy. At Livermore, we focus science and technology on assuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published ten times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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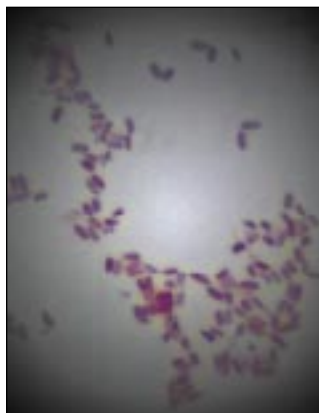
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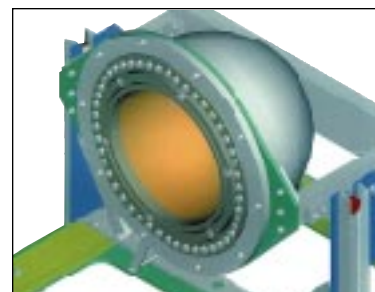
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Tarter testifies before Senate subcommittee

Laboratory Director Bruce Tarter testified before a Senate Armed Services Subcommittee on March 19, 1998. Tarter's prepared testimony focused on stockpile stewardship and on stemming the proliferation of weapons of mass destruction. The text of the prepared testimony is available on Livermore's Web page: http://www.llnl.gov/PAO/cbt6_testimony/.

Tarter said that the Stockpile Stewardship Program, which is intended to help maintain the safety and reliability of the nation's nuclear weapons in the absence of nuclear testing, "is off to a good start." He described how Livermore and other national laboratories have started executing detailed stockpile stewardship plans. For instance, construction is under way at Livermore on the \$1.2-billion National Ignition Facility, an experimental laser designed to provide the means for investigating thermonuclear physics. In addition, a high-performance computer for simulating weapon physics, developed by IBM, is being upgraded to make it the fastest and most capable supercomputer in the world.

Tarter also reported on the Laboratory's efforts to counter the spread of weapons of mass destruction—nuclear, chemical, and biological weapons. He described Livermore's strategy in tackling the challenge posed by these weapons across the entire spectrum of the threat: preventing proliferation at the source, detecting and reversing proliferant activities, and countering terrorism from weapons of mass destruction.

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Nielsen Dillingham awarded \$58-million NIF contract

Nielsen Dillingham Builders of Pleasanton, California, has been awarded a \$58.4-million contract to construct the Target Area Building for the National Ignition Facility (NIF), the world's largest laser. This latest contract is the last major subcontract to be issued for the NIF buildings at the Laboratory. It covers construction of the portion of the facility that will house the target chamber, final optics, and laser switchyard. Included in the work will be the concrete above the mat foundations, the building shell and walls, and interior components for heating, ventilation, air-conditioning, electrical, telephone, and fire alarm systems.

The U.S. Department of Energy's NIF is a stadium-sized, \$1.2-billion, 192-beam laser complex now under construction at Lawrence Livermore. Slated for completion in 2003, the facility will create—for the first time in a laboratory—brief bursts of self-sustaining fusion reactions similar to those occurring in the sun and stars. The resulting data will help DOE maintain the safety and reliability of the nation's nuclear stockpile without nuclear testing while providing

benefits in basic science, astrophysics, and commercial fusion power production.

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Lab supports DOE education initiative

In an effort to prepare high school students for careers in science or math, the Department of Energy, the national laboratories, and the National Science Foundation are spearheading a nationwide program to educate teachers.

Through the National Education Strategy, selected teachers of kindergarten through 12th grade students will use resources of the national laboratories and other DOE facilities to improve the quality of their teaching in science, math, and technology.

"Most of the continued education or professional development teachers get is through classroom lectures, with little opportunity for hands-on work," says Sam Rodriguez, who is leading the effort for DOE. Rodriguez, assistant director of energy research communications and development at DOE, has traveled to laboratories across the nation, coordinating with education leaders on program content. In March, he came to Lawrence Livermore for a series of program development discussions with California school district officials and with members of the Lawrence Livermore, Lawrence Berkeley, and Sandia (Livermore) education programs.

"We're trying to replace static science training for teachers with real science," Rodriguez explained. By letting teachers see and participate in research projects at the various laboratories, "we will be making science come alive for these teachers. We will be building a stronger foundation when these teachers return to their classrooms."

The program will borrow heavily on education outreach programs already in place at the national laboratories and will create new programs between the laboratories and the school systems participating in the National Science Foundation's educational system reform programs.

Through a two-part program, each teacher will get 80 to 100 hours of advanced training in computer and Internet use. The second part of the program will consist of 20 days of hands-on research in applied science and technology development. For those teachers unable to participate in the hands-on research, DOE will team with the National Science Teachers Association to provide general knowledge and understanding of energy science via the Internet. An interactive software program is being developed that will enable on-line volunteers and teachers to exchange information within specific scientific disciplines.

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Deploying Livermore Resources against Biological Weapons

TEN years ago, the consuming national security threat to the U.S. was the nuclear arsenal of the Soviet Union. Virtually all of the energies, talent, and resources of the Laboratory were dedicated to checkmating the Soviet threat, both by ensuring a safe and reliable U.S. nuclear stockpile and by contributing to bilateral strategic arms control agreements. That world no longer exists. The Soviet Union has disappeared, and although a Russian nuclear threat remains, it is greatly diminished, and prospects are favorable for a continuing good relationship with Russia.

Today, the highest priority threat to national security and U.S. forces stems from the proliferation of nuclear, chemical, and biological weapons—the so-called weapons of mass destruction (WMD). Possible perpetrators include rogue states, state-sponsored terrorist groups, domestic terrorists, and even internationally organized criminals and narcotics traffickers. Indeed, more than 50 countries are known to supply, demand, or provide a conduit for WMD devices, materials, and technology.

New technologies and capabilities are needed to deal with the WMD proliferation threat, and nowhere is this more true than for biological weapons. The revolution in bioscience and biotechnology has both heightened awareness of the threat posed by biological weapons and provided the basis for tools to counter it.

The Department of Energy recently established the Chemical and Biological Weapons Nonproliferation Program and is encouraging its rapid implementation and growth. Lawrence Livermore, in cooperation with other national laboratories, is taking an active part in this effort by developing diagnostic methods, detection instrumentation, modeling analyses, and decontamination procedures that prevent and respond to the threat posed by chemical and biological weapons. The Laboratory has many existing capabilities—in remote sensing, detection technologies, forensic science, intelligence analysis, atmospheric science, process modeling systems analysis, hazardous material handling, and bioscience—to apply against this threat. The article beginning on p. 4 reports on specific examples of how Livermore is using these existing capabilities to respond to the bioweapons threat.

The early 1990s saw the development of miniaturized, portable detection instruments at Livermore, and this effort was enhanced in 1996 by a Laboratory Directed Research and Development project to specifically develop instruments for rapid field identification of biological agents. This project culminated in a demonstration of outstanding performance by several biodetectors in Joint Field Trials held at the Dugway Proving Grounds, Utah. On the basis of this success, the Nonproliferation, Arms Control, and International Security and the Biology and Biotechnology Research Program directorates have expanded a collaborative initiative to address the threat of biological weapons.

The principal elements of this effort are systems analysis, biodetector development, and molecular diagnostics. A systems analysis team is working with federal and local representatives to determine where to deploy detectors and to develop incident response scenarios; these activities also provide valuable information for improving biodetector performance and operation. In biodetector development, researchers are continuing to decrease the size and increase the sensitivity of the instruments, with an emphasis on autonomous detection systems or “sentries.” Molecular diagnostics research is contributing to the fundamental understanding of biological threat organisms needed for optimum incident response and attribution. This information will also be used to improve pathogen detection assays and to assist other agencies in the development of effective preventative and therapeutic medical treatments.

As a national security laboratory, Lawrence Livermore is building on its established programs and its historical nuclear weapons mission to address the threat posed by biological weapons. This most recent initiative typifies the Laboratory’s multidisciplinary, cross-cutting approach to applied science and its ability to anticipate and respond to national security needs.

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Reducing the Threat of Biological Weapons

Livermore's strategy for defense against the use of biological weapons integrates technology, operations, and policy and provides a framework for coordinated local, state, and federal emergency response.

"WEAPONS of mass destruction" is a terrifying term. We all have mental images of the horrors of a nuclear attack, and photos of Kurdish and Iranian casualties of Iraqi chemical attacks attest to the devastation of chemical weapons. The third weapon of mass destruction—the biological weapon—has been around at least since the Middle Ages when soldiers catapulted the bodies of dead smallpox victims over fortress walls in the hope of infecting their enemies or at least demoralizing them.

Lately, biological weapons have been appearing in the news with increasing frequency. The anthrax threat in Las Vegas in February of this year is an example. Surplus stores in Las Vegas sold out of gas masks, and talk-radio shows were swamped with callers asking about evacuation points. That threat turned out to be a false alarm, but the next one might be real.

Biological agents are of concern in part because of the ease with which many of them can be manufactured, transported, and dispensed. And because of the lag time between a biological attack and the appearance of symptoms in those exposed, biological weapons could be devastating. Many biological agents are contagious, and during this lag time, infected persons could continue to spread the disease, further increasing its reach. Hundreds or

even thousands of people could become sick or die if a biological attack were to occur in a major metropolitan area.

With the knowledge that several nations have produced and perhaps also deployed biological warfare agents, Congress in 1996 passed the Defense Against Weapons of Mass Destruction Act, which authorizes the Department of Energy to establish a Chemical and Biological Weapons Nonproliferation Program. Under this and similar programs, Lawrence Livermore and other laboratories and institutions are working together to increase this country's capabilities to detect and respond to an attack by biological or chemical weapons.

Beginning as recently as Fiscal Year 1996 with a Laboratory Directed Research and Development strategic initiative, Livermore has rapidly expanded its chemical and biological nonproliferation program and is now playing a lead role in this effort, particularly as it pertains to defense against biological weapons. The Laboratory is applying its investment in biological science, engineering, microtechnology, computer modeling, systems analysis, and atmospheric science to a number of programs designed to improve the country's response to a biological attack. Personnel from departments and directorates across the Laboratory are at work on:

- Advanced detection systems to provide early warning, identify populations at risk and contaminated areas, and facilitate prompt treatment.
- Biological forensics technologies to identify the agent, its geographical origin, and/or the initial source of infection.
- Methods for predicting the transport



of biological agents in urban environments and for assessing the area and duration of the hazards associated with a biological attack.

- New decontamination technologies to clean and restore facilities without causing further environmental damage.

Livermore is working closely with the U.S. military, various government agencies, and such major cities as New York City and Los Angeles to ensure that the results of these biological nonproliferation efforts meet the needs of military troops, the FBI, local law enforcement personnel, fire fighters, public health officials, and others who would likely be first on the scene following a biological attack. Together these groups are answering questions to help create the best, most task-appropriate, and most usable system possible. For example, how accurate do sensors have to be? What level of false alarms can be tolerated? Where will sensors be located—in buildings, on emergency response personnel, or at other sites? How much training will be feasible for emergency response personnel on the use of sensors and decontamination agents—that is, how user-friendly must these processes be?

Livermore is developing a strategy for defense against the use of biological weapons that integrates technology, operations, and policy and provides a framework for coordinated local, state, and federal emergency response.

Better Detection Systems

A key factor limiting the nation's ability to protect against a biological attack has been the state of biodetector technology. Only now is technology becoming available that permits identification of biological organisms within minutes, when concentrations are low but often still dangerous. Before the revolutions in genomics, biotechnology, microengineering, and microcomputers, such identification could only be done



Figure 1. Ray Mariella, Jr., working with a multichambered PCR (polymerase chain reaction) unit. In the 1997 Advanced Concept Technology Demonstration, this PCR instrument proved an effective tool for field identification of the DNA in nonvirulent bioagent simulants.

in a laboratory and took days to weeks. Soon, however, technology advances—many of them made at Lawrence Livermore—will offer the possibility of rapid, accurate, and sensitive biodetectors for use in battlefield or urban settings.

Automation Is Key

Livermore is developing two types of fully automated biodetectors for real-time sample collection, detection, and identification in the field. A miniature flow cytometer (known as miniFlo) uses an immunoassay system to look at the proteins and other material on the surface of cells, and a portable PCR (polymerase chain reaction) unit identifies the DNA inside the cell. (See the [box on p. 6](#) for more information on these systems.) Because of their small size and efficiency, both units process data much faster than their laboratory-scale cousins, while maintaining the highest level of sensitivity.

To fully automate sample collection and preparation, Livermore is developing and testing components for an aerosol biocollector and a microfluidic sample preparation system. The device will collect and sample particles in the air, including biological agents, if present. To maximize detection potential and give faster results, the PCR unit and miniFlo are also being “multiplexed” to

handle multiple samples at once. Other system improvements are being made to both instruments to lower the rate of false positives (false alarms), increase the sensors' sensitivity, and make the systems even smaller, more rugged, and less reliant on consumables than they are now. Livermore expects to have continuously operating, integrated biosensors available for use within the next few years.

With two types of sensors working in tandem, the chance of false alarms will be reduced considerably. Tolerance for false alarms differs greatly for military versus civilian situations. Deployed troops are already in a state of heightened readiness, with protective equipment available and the training required to react to attack situations. In contrast, with civilians, false alarms could lead to injuries and perhaps to dismissal of future legitimate alarms. Thus the military may be able to afford some level of false alarms, but the goal for the civilian sector is no false alarms.

The miniFlo and the PCR systems have proved their mettle against established performance criteria at the U.S. Army's international Joint Field Trials at the Dugway Proving Grounds in Utah. At Dugway, participants use a variety of instruments to detect simulant materials representative of typical biological weapon materials.

At the 1996 Joint Field Trials III, miniFlo was superb at detecting *Bacillus globigii* and *Erwinia herbicola* (nontoxic simulants for anthrax and plague respectively) at various low concentrations. Overall, miniFlo detected 87% of all unknowns with a false alarm rate of under 0.5%. At the 1997 Port/Airbase Advanced Concept Technology Demonstration and the January 1998 Dugway Joint Field Trials IV, the portable PCR unit clearly demonstrated the potential of PCR as an effective technique for field identification of DNA ([Figure 1](#)).

Networked Detectors

A networked system of these or other biodetectors could provide U.S. troops in the field with early warning of a biological attack. That is the goal of a project for the Department of Defense known as JBREWS (Joint Biological Remote Early Warning System), on which Livermore is collaborating with Johns Hopkins Applied Physics Laboratory and Los Alamos National Laboratory. As shown in **Figure 2**, JBREWS will consist of a network of sensors and communication links. By tying this network into the military's existing communications systems, JBREWS will take advantage of well-established command and communications procedures. Initially

equipped with commercially available sensors, JBREWS is being configured so that improved biodetectors can be incorporated into the system as they become available.

Livermore is responsible for what is known as "C4I"—command, control, communications, computers, and intelligence. The Laboratory is developing the connectivity between the sensors and the control station, the software for all sensors, and an automatic analysis and reporting system that runs up through the military chain of command. JBREWS is scheduled to be demonstrated in a Department of Defense Advanced Concept Technology Demonstration in 1998.

Biological Forensics at Work

If a bacterium or spore appears in a collected sample, how will a biodetector know what it is? The key to identification will be a library of "signatures" of the makeup, function, and DNA of various biological agents that will be stored on a microchip in the detector, together with pattern-matching software and code for reporting results. This technology will allow advanced detectors in the laboratory and ultimately in the field to quickly match the signatures of collected particles to signatures in its memory, in much the same way that fingerprints are matched.

Building on years of experience in genomics and biotechnology, Livermore scientists are expanding the

Livermore's New Biodetectors

Portable PCR

In late 1996, Lawrence Livermore delivered to the U.S. Army the first fully portable, battery-powered, real-time DNA analysis system. DNA analysis requires many copies of a DNA sample, which are made by the polymerase chain reaction. PCR requires repeated cycles of an aqueous sample being heated close to the boiling point and then cooled. To detect DNA in a sample, a synthesized DNA probe or primer tagged with a fluorescent dye is introduced into the sample before it is inserted into the heater chamber. Each probe or primer is designed to attach to a specific organism—anthrax, plague, etc. If that organism is present in the sample, the probe attaches to its DNA. By measuring the sample's fluorescence, the instrument reports the presence (or absence) of the targeted organism.

In Livermore's portable unit, the thermal cycling process takes place in a micromachined, silicon heater chamber that has integrated heaters, cooling surfaces, and windows through which detection takes place. The PCR reaction and DNA analysis take place in a disposable polypropylene reaction tube inserted into the heater chamber.

Because of the low thermal mass and integrated nature of Livermore's silicon heater chambers, they require very low power and can be heated and cooled much faster than conventional units. So the unit is not only portable but also much faster and more energy-efficient than bench-top models. A multiple-chamber unit that allows the examination of many samples at the same time has been field tested.

MiniFlo

Livermore's miniature flow cytometer is the latest in a series of flow cytometers developed over the past two decades in Livermore's Biology and Biotechnology Research Program Directorate. Flow cytometers are used in laboratories to analyze cells and their features, perform blood typing, test for diseases and viruses, and separate out particular cells or chromosomes. What sets miniFlo apart from other flow cytometers is its small size, portability, and sensitivity.

These features are made possible by a novel system that eases the alignment and increases the accuracy of flow cytometry. In a flow cytometer, the cells flow in single file in solution while the experimenter directs one or more beams of laser light at them and observes the scattered light, which is caused by variations in the cells or DNA. Instead of using a microscope lens or an externally positioned optical fiber as a detector, this method uses the flow stream itself as a waveguide for the laser light, capturing the light and transmitting it to an optical detector. This approach not only eliminates the alignment problems that plague traditional flow cytometers but also collects ten times more light than a microscope lens does. Simpler alignment and more light mean better, faster analysis.

Bacteria are large enough for individual detection in the miniFlo, but viruses and proteins are not. So beads large enough to be detected are coated with an antibody and added to the sample. The virus or protein attaches itself to the bead and can then be detected. When different beads are coated with different antibodies, simultaneous detection of several biological agents is possible.



Figure 2. Livermore scientists are designing the Joint Biological Remote Early Warning System (JBREWS) for the Department of Defense to give early warning to troops in the field in the event of a biological attack. JBREWS uses a networked system of sensors that automatically report to a central computerized command post.

information base of the DNA sequences of biological agents to enable rapid, unambiguous identification of biological agents. To facilitate this process, they are developing ways to speed up the process of finding unique DNA sequences among organisms.

A process known as representational difference analysis helps to identify unique DNA sequences. Parts of the DNA of two organisms are mixed. If they stick together, they match; if they do not stick, they are unique parts. Currently, this process is cumbersome and slow, but Livermore scientists are working to automate it to be able to examine many sequences in parallel.

Another project is studying specific pieces of bacterial DNA and examining the possibility of using their location as an indicator of differences among strains. A third project is investigating virulence factors, which are the genes that give a biological organism its infectivity or toxicity. If a bioweapon is being genetically engineered, those genes might be moved to an unnatural host in an attempt to thwart detection and identification.

In addition to identifying the particular agent being used, tools being

developed at Livermore also seek to provide information that will help to identify the perpetrator of a biological attack. Livermore biomedical researchers were among the first to study regional differences among the various naturally occurring strains of anthrax and other biological agents. Law enforcement personnel will be able to match data about a pathogen with data on regional or strain characteristics (indicators of engineered characteristics) and with data on worldwide biological research, epidemiology, and infectious diseases and respond to the threat.

Predicting Agent Dispersion

The ability to accurately predict the dispersion, concentration, and ultimate fate of biological agents released into the environment is essential to prepare for and respond to a biological agent release. Of particular concern is the threat to civilian populations within major urban areas where potential terrorist incidents are more likely to occur. There the hazard from a biological-agent release could be confined to a localized area within or around a single building or extend out to a large portion of the city or even into the surrounding suburbs,

depending on the particular agent release, the quantity and duration of the release, and the meteorological conditions under which dispersion of the agent occurs.

Computer simulations of biological releases are critical to the design and placement of biosensor systems. They also aid in risk assessment, disaster planning, and emergency response training (Figures 3 and 4). If a biological release were to occur, real-time predictions of agent concentrations would be used to characterize the source, estimate exposure levels, identify affected areas and best evacuation routes, and later assist with decontamination. Accurate information about the likely course of a bioagent attack is key for emergency response managers, who must notify health officials, inform emergency response teams, and make public safety decisions.

The urban biological release problem is quite complex and requires modeling capabilities that are still in the early stages of development and application. For example, models of airflow inside buildings and subways have been developed to some degree but do not accurately incorporate the decrease in airborne concentration that results from deposition of the toxic material on walls, ceilings, ventilation ducts, and other interior surfaces. Similarly, computational fluid dynamics models of the highly distorted flows and dispersion patterns created by complexes of buildings are just beginning to include the effects of biological aerosols (gravitational settling, deposition, and viability degradation) and multiple building interactions.

Lawrence Livermore, Lawrence Berkeley, Los Alamos, and Argonne

national laboratories are working together to develop an integrated and validated atmospheric modeling capability for biological agent releases in an urban environment. They will be applying these models to case studies in a range of release scenarios, from closed office buildings, to subway

systems, to stadiums and street corners. The goal is to make the models applicable to real-life situations and ultimately to integrate them into the incident response capability of the National Atmospheric Release Advisory Center, located at and operated by Lawrence Livermore.

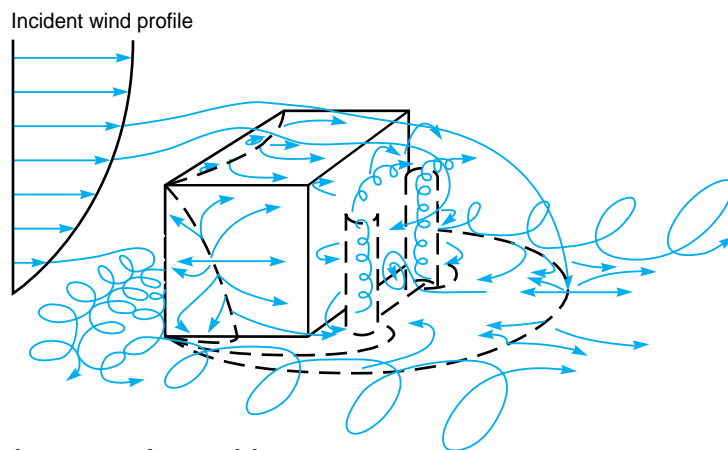


Figure 3. Developing atmospheric models for an urban setting requires taking many flow patterns into consideration. As shown here, air movement around just one building is highly complex.

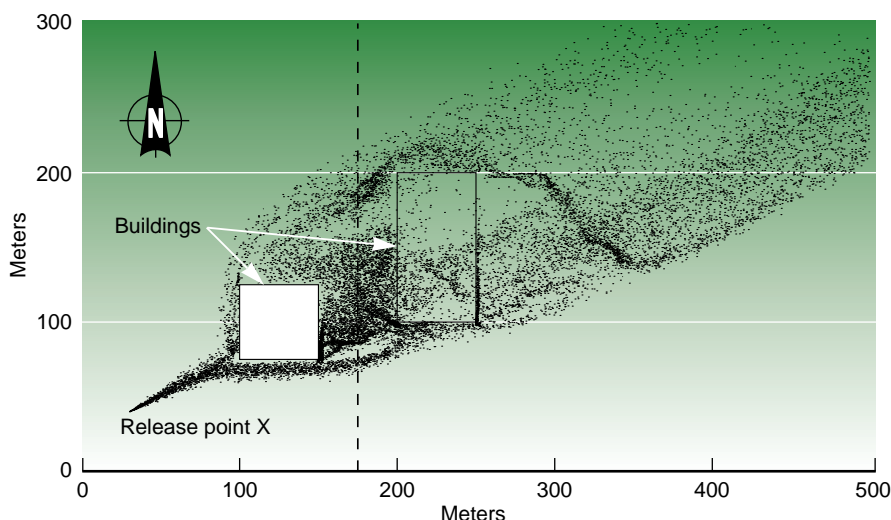


Figure 4. This scenario shows where particles will be 10 minutes after they are released at point X in a 240-degree (west southwest) wind of 10 meters per second. Several areas of high particle concentration are visible to the south of the two buildings, with lesser concentrations to the north and to the east.

Decontaminating a Site

After an area has been exposed to a biological attack, it must be decontaminated before it can be reopened to the public. Livermore and Los Alamos national laboratories are working together to develop decontamination strategies for three scenarios—an open stadium, a semi-enclosed subway, and an enclosed area such as an office or home. Certain decontamination methods might be acceptable for one scenario but not another. For example, more corrosive reagents and large volumes of water might be acceptable in a stadium but could not be used in an office building.

Plain household bleach is one of the best decontamination agents around, and it is used regularly in biological laboratories throughout the country. But 5% sodium hypochlorite (as bleach is more technically known) is a very caustic product, so it must be used with care. The team is working to develop decontamination methods that are as effective as bleach but more acceptable environmentally.

Decontamination proceeds in several stages, from cleanup of gross contamination such as puddles of agent, to localized decontamination of walls or furniture that were directly exposed to the agent, to cleanup of ductwork or inaccessible cracks for hidden contamination, and finally to long-term remediation such as special paints or sorbents to destroy small quantities of agent that are left after completion of other decontamination. These stages may require different cleanup materials. A variety of liquids and powders are being studied, as is an array of delivery methods such as foams and gels. One treatment method that has been found to be effective and more environmentally acceptable than hypochlorite (an alkaline product) is peroxymonosulfate, which is an acidic oxidizer. **Figure 5** compares treatment of a simulant for anthrax with these

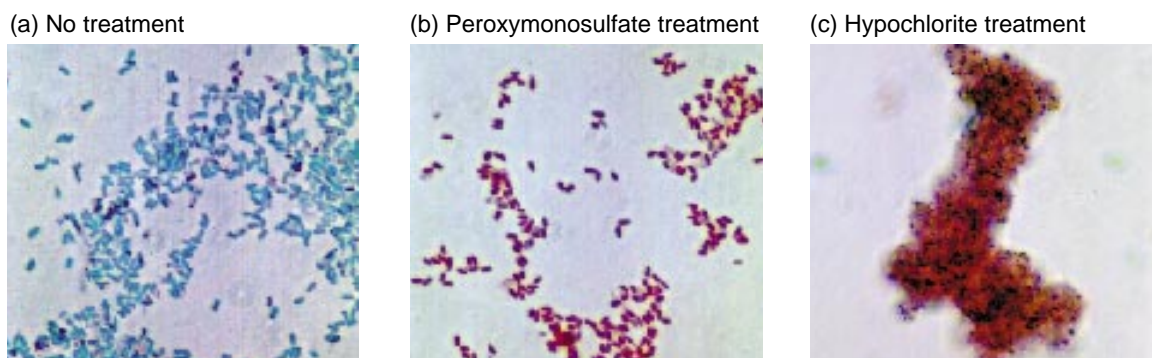


Figure 5. *Bacillus globigii* spores (a simulant of the spores that cause anthrax) are shown (a) before and (b) after a 30-minute exposure at 22°C to peroxymonosulfate, an acid oxidizer, and (c) after treatment with hypochlorite, an alkaline oxidizer. Spores were stained with malachite green (blue-green) and safranin (red) dyes. Safranin dye penetrates only dead spores because of their damaged walls, thus making it a good indicator of the effectiveness of a biocide.

oxides. The selected method must be not only effective but also easy to use with minimal training.

The social and political issues involved in decontamination and reentry to a site are not being overlooked. Central to these concerns is “How clean is clean enough?” The team is coordinating with the biosensor developers to devise sampling and analysis systems that can verify that decontamination is complete.

One hurdle for the decontamination process is that no real-time biotector currently under development at Livermore uses an assay that can distinguish between viable organisms and dead or decontaminated ones. Work has begun on a “viability assay” based on flow cytometry to provide this important piece of information so that decontamination can proceed in a timely manner.

Responding to the Threat

The threat of biological weapons is all too real, and the U.S. must be prepared to respond if a bioattack occurs on the battlefield or in a civilian setting. During the 1991 Gulf War, the U.S. had no systems available for rapid, timely field detection of bioagents. The situation

today is very different. The military has deployed Biological Integrated Detection Systems (BIDS), which can tentatively identify the presence of a suspected biological agent in the field and warn soldiers to take appropriate action to protect themselves against the agent, pending positive laboratory identification. And there are also programs such as Livermore’s that include new detection, identification, atmospheric modeling, and decontamination capabilities, which, combined with work by others on better vaccines and medical treatment, are bringing the country to a level of

preparedness that can meet a biological threat.

—Katie Walter

Key Words: biotectors, bioinformatics, biological warfare agents, decontamination, DNA analysis, flow cytometry, genomics, miniFlo cytometer, National Atmospheric Release Advisory Center (NARAC), polymerase chain reaction (PCR), weapons of mass destruction (WMD).

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About the Scientist



FRED MILANOVICH received his B.S. in physics from the United States Air Force Academy in 1967 and a Ph.D. in applied physics from the University of California at Davis in 1974. He is currently program manager for the Chemical/Biological Nonproliferation Program within the Nonproliferation, Arms Control, and International Security Directorate at the Laboratory. This program is providing an integrated response to the emerging threat of chemical and biological terrorism with innovation in detection technology, bioinformatics, fate and transport analyses, and incident response. Milanovich has published extensively in his field and holds many patents for optical sensors and measurement instruments. His research interests also include trace biotector, laser spectroscopy, analytical instrumentation development, and microtechnology.

At the Crossroads of Technology and Policy



The Center for Global Security Research brings together policymakers and scientists to enhance national and world security.

WHEN Attorney General Janet Reno announced the establishment last February of a new FBI center to investigate and prevent attacks on the nation's critical infrastructure, she did not appear at Department of Justice headquarters in Washington, D.C. Instead, she chose to make her announcement at a Lawrence Livermore workshop co-sponsored by a small organization that is attracting increasing attention from top scientists and government policymakers worldwide.

That organization is Livermore's Center for Global Security Research (CGSR), established in 1996 to bring the

technology and policy communities closer together. Its goal is to reduce threats to international security, especially those associated with weapons of mass destruction, by sponsoring workshops, research fellows, and independent analyses to study important national and world security issues involving policy and technology.

CGSR Director Ron Lehman says the Center's "product" is fresh insight into some of the most vexing national security issues. Lehman notes that the Center is not afraid of getting into sensitive areas, but he emphasizes the need for fellows and participants to be



fiercely independent in their work, intellectually rigorous, and dedicated to hearing from an uncommonly broad range of viewpoints and backgrounds.

February's critical infrastructure workshop, for example, co-sponsored by Stanford University's Center for International Security and Arms Control, brought together a wide range of representatives from business, government, and technology (see box, pp. 14–15). They addressed ways to protect the nation's banking, communication, computer, and power networks from a host of potential adversaries, ranging from state-sponsored foreign terrorists to youthful hackers.

The workshop was but one illustration of CGSR's practice of joining Livermore scientists and engineers with other technical experts, academics, policymakers, military leaders, and industry executives to address issues involving national security technology and policy. Past workshop topics have included chemical and biological weapons terrorism, nuclear materials smuggling, relations with Russian nuclear

scientists, the future of nuclear forces, and environmental security.

Small Is Good

The CGSR is deliberately small; there are no permanent employees other than administrator Karen Kimball. Lehman and half-time special assistant Eileen Vergino, a seismologist, are on rotation while retaining other responsibilities at Livermore. The Center invites Livermore specialists and outside scientists to work together on specific tasks for a limited time, publish their findings, and then return to their main activities. "I think of us as a think tank constantly reorganizing itself as it takes on new tasks," Lehman says.

Lehman is the first to point out that the nation has no shortage of think tanks and national security study centers. The uniqueness of CGSR, however, derives from its close affiliation with Lawrence Livermore, one of the few U.S. institutions with expertise in all phases of nuclear weapons development. Lehman cites Livermore's strengths in analysis, modeling, and computer simulation as important resources that are regularly tapped for CGSR-

sponsored research. The [table on p. 12](#) summarizes the Center's multidisciplinary support from all Laboratory directorates.

While Lehman reports to Livermore Director Bruce Tarter, the CGSR is part of the Nonproliferation, Arms Control, and International Security (NAI) Directorate. The Center's activities complement the diverse efforts of NAI specialists to prevent the proliferation of weapons of mass destruction, assist in arms control matters, and build stronger relations with scientists of the newly independent states of the former Soviet Union.

As CGSR director, Lehman relies regularly on his diplomatic experience with and knowledge of arms control issues. Before joining Lawrence Livermore in 1993, he served as director of the U.S. Arms Control and Disarmament Agency, Assistant Secretary of Defense for International Security Policy, Deputy Assistant to the President for National Security Affairs, and U.S. Chief Negotiator for the Strategic Arms Reduction Treaty I.

Lehman also chairs the governing board of the International Science and

The critical infrastructure workshop at Lawrence Livermore in February 1998 featured a panel discussion on ways to protect the nation's critical banking, communications, computer, and power networks from a variety of terrorist attacks. Panelists were (left to right): George Spix of Microsoft; Scott Penberthy from IBM; Tom Marsh, chairman of the Commission on Critical Infrastructure Protection; former Secretary of Defense William Perry; Philip Bobbitt from the National Security Council; David Cooper, Lawrence Livermore's Associate Director for Computation and Chief Information Officer; Ron Lee, Department of Justice; and Anita Jones, a professor at the University of Virginia. (Above) Former Defense Secretary Perry makes a point during the panel discussion.



Ron Lehman, Director of the Center for Global Security Research, works with administrator Karen Kimball (right) and scientist Eileen Vergino to plan one of the Center's diverse national security activities.

Technology Center (ISTC). Established in 1994 and headquartered in Moscow, the ISTC is funded by several Western countries. It is working to prevent the dispersion of knowledge related to weapons of mass destruction by financing nonweapons projects that integrate weapons specialists from the newly independent states of the former Soviet Union into the international scientific community. Both Lehman and Vergino, a scientific advisor to the ISTC, travel regularly to Moscow for ISTC meetings. (For more on the ISTC, see the [September 1997 S&TR](#), pp. 19–20.)

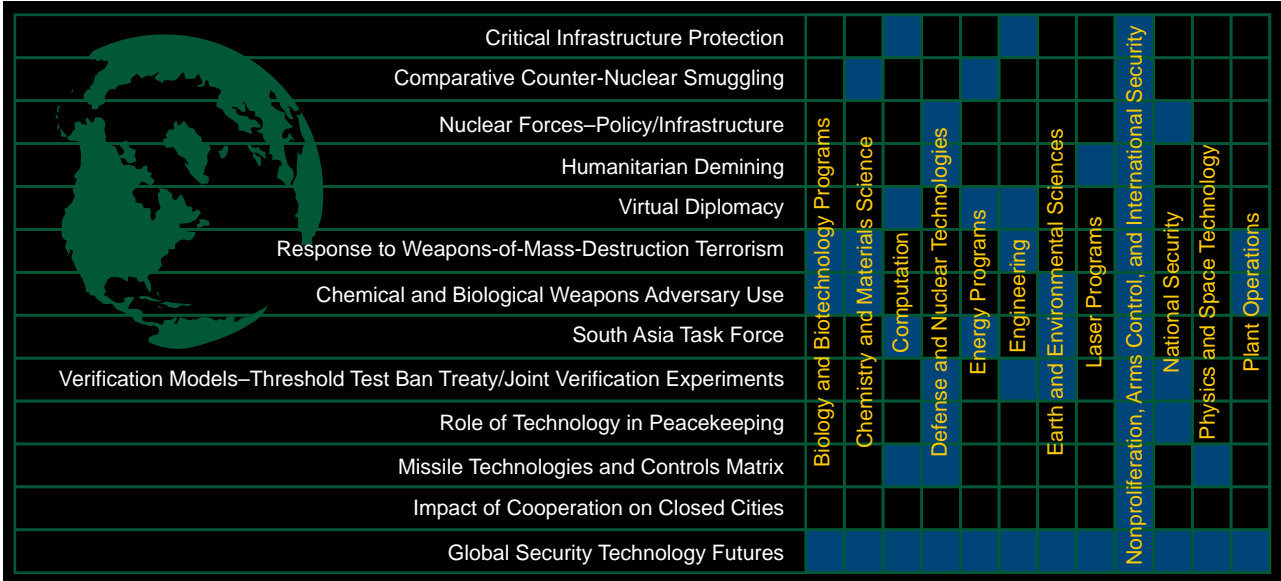
An International Perspective

The CGSR’s international viewpoint is evident in its workshops, such as a seismic forum held last year involving Jordanian and Israeli scientists. Indeed, the Center’s inaugural conference, “Meeting the Challenges of International Peace Operations: Assessing the Contributions of Technology,” established a precedent when it attracted United Nations field commanders from around the globe to Livermore.

Former NAI Associate Director Bob Andrews led the effort to create the CGSR. At its inauguration, Andrews said, “Although the Laboratory has been a key player in providing technology support to U.S. and international agencies, we have not been as well connected to the policy community as we might. . . . Even the most clever and sophisticated technology must be assessed in terms of the overall policy framework, including options that it may or may not make available.”

Those associated with CGSR activities hail its value as an educational and networking resource for both Livermore scientists and national policymakers. “We want to bridge the gap between the technology and policy communities,” Lehman explains.

Livermore physicist Don Prosnitz, chief NAI scientist, is involving more NAI employees in CGSR activities because the interchange between technologists and policymakers is so valuable. “We want to get technologists into policy forums so that they understand the policy influences of the technology they’re developing. We also



The Center for Global Security Research taps into expertise from across the Laboratory.

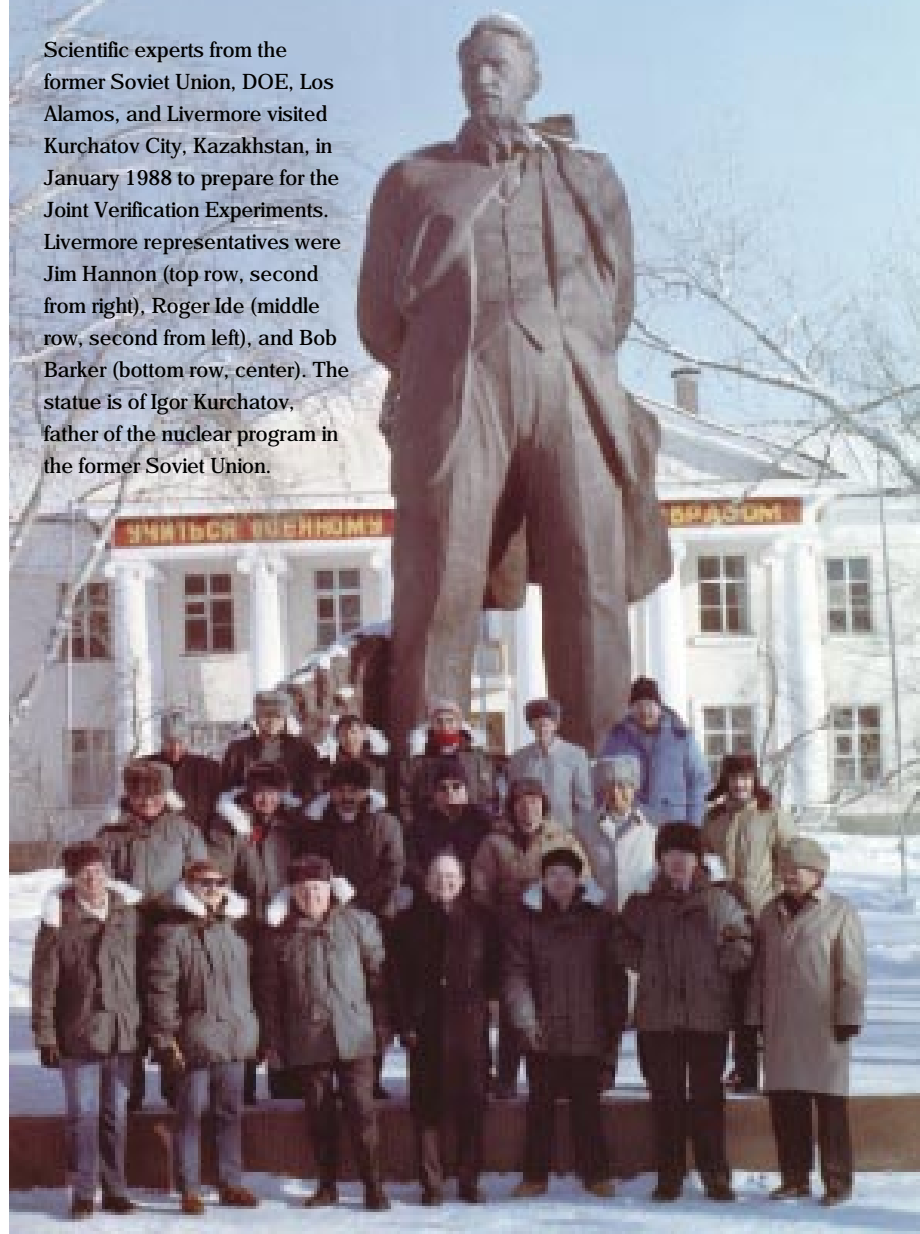
want to expose policy types to technologists so that they understand the limitations of technology.”

Lehman notes that having an international perspective encourages examination of the cross-cultural aspects of security issues—with often surprising results. A 1997 workshop on protecting fissile materials, co-hosted by CGSR, Stanford University’s Center for International Security and Arms Control, and the Monterey Institute of International Studies, revealed striking cultural differences. After workshop participants heard some experts explain the need for shock troops and air defenses to protect fissile-material storage centers, a Japanese representative noted that in his country, armed guards had long been disdained because once someone in Japan trusts another, it is considered very impolite (and a violation of that trust) to verify. Meanwhile, a South Asian speaker cited a similar cultural problem when guards of one social class must, as a part of their jobs, search the briefcases of scientists and officials of higher social classes.

Livermore chemist Jeff Richardson, principal deputy program leader in NAI, helped organize two workshops on fissile materials smuggling with the U.S. Air Force Institute for National Security Studies. Characteristic of CGSR activities, attendees represented major federal agencies, U.S. study centers, and representatives from France, Poland, Kazakhstan, Russia, the London Metropolitan Police, and even the Public Broadcasting System. “The Center provides the right forum for these kinds of interchanges,” says Richardson. “It is an excellent opportunity to facilitate interactions on a global scale.”

Case Study of the TTBT

This year, the CGSR began a case study in verification methodology by reviewing the events leading to the signing of the Threshold Test Ban Treaty



Scientific experts from the former Soviet Union, DOE, Los Alamos, and Livermore visited Kurchatov City, Kazakhstan, in January 1988 to prepare for the Joint Verification Experiments. Livermore representatives were Jim Hannon (top row, second from right), Roger Ide (middle row, second from left), and Bob Barker (bottom row, center). The statue is of Igor Kurchatov, father of the nuclear program in the former Soviet Union.

(TTBT), which limited underground nuclear tests to 150 kilotons. Although negotiated in 1974, the treaty was ratified by the U.S. Senate in 1990 only after the establishment of a strict verification protocol with the Soviet Union. That protocol included the historic Joint Verification Experiments (JVE), whereby Soviet and U.S. teams for the first time

conducted on-site yield measurements at each other’s nuclear test sites.

“There is a tremendous richness of ideas and history associated with the TTBT,” says Lehman. “It seemed useful to do a case study and look at the evolution of our thinking regarding the treaty and the meaning of ‘adequate and effective’ verification.”

Vergino, who provided technical support to the U.S. delegates in Geneva during the treaty's protracted negotiations, is leading the study. She is being assisted by many of the principals involved in the treaty process, including specialists from Lawrence Livermore, Los Alamos National Laboratory, the Department of Energy, and the State Department.

"We believe our study may provide lessons for the future," says Vergino. "JVE was a turning point in Soviet relations with the West. Many American-Russian friendships were forged, and the more open atmosphere anticipated the post-Cold War era."

She also notes that Livermore played a leading role in organizing the "Lab-to-Lab" interactions with the Russian nuclear institutes in the formerly closed Russian cities during that time. That relationship has expanded to include the exchange of electronic mail between Russian schoolchildren living in those cities and Livermore children in a program Vergino helped establish. (For other details on the Lab-to-Lab program, see the *September 1997 S&TR*, pp. 18-19.)

Vergino is hopeful that the Center's TTBT study will be ready in time to share with Russian colleagues at a 10-year JVE jubilee celebration being

planned for this summer in Kazakhstan as well as at a technical exchange meeting also planned for this summer in Nevada. The CGSR is helping to coordinate American participation in the jubilee.

Another arms agreement receiving particular CGSR attention is the Convention on the Prohibition on the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction. Prosnitz has worked with the Center on three meetings devoted to various aspects of the treaty. "It's a very important treaty because it bans an entire class of

Preventing Attacks on the Nation's Critical Infrastructures

How vulnerable to cyber and physical attack are the nation's emergency services and telecommunications, electrical power, gas and oil storage, banking and finance, transportation, and water supply systems? In July 1996, President Clinton established the Commission on Critical Infrastructure Protection to assess the vulnerabilities and recommend ways of protecting these essential resources.

To examine many of the issues connected with the Commission's work, Lawrence Livermore's Center for Global Security Research (CGSR) and Stanford University's Center for International Security and Arms Control conducted two workshops at Stanford in March and July 1997. The workshops were attended by top-level representatives from government, industry, and academia. Participants also included Commission members and staff, who told CGSR Director Ron Lehman that they found the workshops invaluable in the preparation of their October 1997 final report.

Livermore senior engineer Stan Trost was instrumental in working with the two centers to sponsor the series. "If critical infrastructures like the Internet and phone system go down, the country is in trouble," says Trost. "We wanted a 'safe' place for participants, especially corporate and government representatives, to discuss their common concerns."

The Commission's final report identified significant vulnerabilities in the nation's critical infrastructures. It recommended an effort to educate the American public and industry; a broad program of cooperation and information sharing between government and industry; reconsideration of laws related to infrastructure protection; the strengthening of research and



Attorney General Janet Reno announces the formation of the National Infrastructure Protection Center during her visit to the Laboratory in late February 1998.

development; and the establishment of a national organization dedicated to all aspects of critical infrastructure protection.

Implementing Recommendations

According to Lehman, the present task is to determine the best ways to implement the commission's recommendations. That was the focus of the series' third workshop, held at Lawrence Livermore on February 26 and 27, 1998. Workshop participants included William J. Perry, former Secretary of Defense; Tom Marsh, Commission Chairman; Michael May, co-director of Stanford University's Center

weapons, but it has no teeth,” he says. One workshop focused on ways to strengthen inspection protocols with on-site biological sampling, while another explored ways for nations to cooperate if terrorists ever used biological weapons.

The CGSR invites Laboratory scientists—and those at other institutions—to apply for fellowships to pursue original research in one of four focus areas: management, control, and reduction of threats associated with weapons of mass destruction; security implications of emerging technologies such as biological and chemical weapons; threat anticipation and

management; and the future role of military forces. A review committee recommends proposals for funding.

“We want research topics that leverage the talents and resources at LLNL,” says Lehman. Visiting fellows are especially encouraged to seek broad interaction with Livermore employees. For example, Ken Weiss, formerly of the Arms Control and Disarmament Agency, is working with NAI specialists on issues concerning missile technology control. Previously, Jim Walsh from the Massachusetts Institute of Technology examined why fewer nations than originally predicted had acquired nuclear weapons.

Ridding the World of Mines

From within the Laboratory, physicist David Eimerl of the Laser Programs Directorate is doing a systems analysis of humanitarian demining as a half-time Center fellow. Recently, Eimerl chaired a CGSR-sponsored conference on technological solutions for clearing land mines. “There is a lack of coordination between the people who are on the front lines and those who are in labs developing the technologies. The workshop was a great way to get us educated.”

He notes that the technological requirements posed by demining are

for International Security and Arms Control; Bruce Tarter, Lawrence Livermore Director; David Cooper, Livermore Associate Director for Computation; and representatives from RAND Corp., the White House Office of Science and Technology Policy, Cisco Systems Inc., Microsoft, Stanford University, University of Virginia, Blue Shield, the National Security Council, DOE’s Office of Nonproliferation and National Security, the Department of Energy, the Department of Defense, SRI International, Sandia National Laboratories, U.S. Telephone Association, and others.

In her keynote address televised to Livermore employees, Reno warned that the nation’s critical infrastructures have become “more vulnerable than ever before as we come to rely on technology as never before.” As a result, she said, “I think this is the most extraordinarily challenging time that law enforcement has ever faced.”

Reno said some of today’s criminals “don’t have guns; they have computers, and they may have . . . weapons of mass destruction.” She said that to appreciate the dimensions of the problem, one only has to realize that “someone could sit in a kitchen in St. Petersburg, Russia, and steal from a bank in New York.”

She noted that the Livermore workshop could not be more timely because the Administration was, at that moment, engaged in determining how to implement the Commission’s report. She underscored the importance of the Commission’s recommendation of a broad national partnership to ensure the protection of critical networks and systems.

Partnerships Work

Such partnerships do work, Reno emphasized, pointing to a recent New York hacker case that teamed the FBI, the Secret

Service, Nynex, Southwest Bell, other private companies, and several universities to identify and prosecute individuals who had hacked into a telecommunications network, a credit reporting company, and other systems.

To promote partnerships and strengthen existing resources, Reno announced the establishment of the FBI’s National Infrastructure Protection Center to detect, prevent, and respond to cyber and physical attacks on the nation’s critical infrastructure. The new organization, she said, will include representatives from federal agencies and the intelligence community. She expressed hope that the private sector would be an active participant in the new center as well.

The Attorney General said the federal government must also work with scientists as partners “to develop technologies and processes that enable us to obtain evidence in strict adherence to the fundamental protections guaranteed our citizens by the Constitution.” She suggested that scientists may need to work together with Fourth Amendment (protection from unlawful search and seizure) experts.

In conclusion, Reno said her visit to Lawrence Livermore was “extraordinarily helpful” and had convinced her that “based on the example of what you do here, we can make a difference. . . . Thank you so very much for setting an example.”

Lehman is hopeful that Lawrence Livermore will play a significant role in helping to implement the Commission’s findings. For example, its expertise in computer simulation for computer security applications has drawn significant interest from workshop participants and Commission members.

particularly daunting. “Demining is not like prospecting for gold. If you find some gold, even if you don’t find all of it, you’re happy. But with demining, you have to find all the mines; you can’t miss a single mine. Doing anything 100% is an incredible challenge.”

Eimerl says that demining also involves fascinating policy issues and human, international, national, and political dimensions. After traveling to Bosnia, for example, he discovered that although the thousands of buried mines there pose a threat to the population, they also serve to keep borders intact and help to discourage an attack from neighboring rival factions. Despite the complexities of the demining problem, he believes that “Livermore, with its intellectual and technical smarts, is the right place to take on this issue, and the Center is the right place to look at the nexus of policy, technology, and security.”

Looking to the Future

“We want the work done at the Center to be valued and respected by the best minds and institutions around the world,” says Lehman. To accomplish that, he says, means reaching out more to University of California campuses and other academic institutions, as well as to industry, government, and international organizations.

The Center is also looking for ways to make its work more accessible. Lehman’s goal is to have all of the

research papers and workshop reports placed on the CGSR World Wide Web site (www.llnl.gov/nai/cgsr-home). He is also working with the University of California Institute on Global Conflict and Cooperation to use the Internet for electronic conferencing, part of a proposed “virtual diplomacy” initiative.

Lehman says the best measure of the Center’s success is the degree to which senior officials and top-ranking experts desire to be CGSR participants and fellows and the interest, inside Lawrence Livermore and out, in using the fresh insights from its studies and workshops. Judging by recent history, including Janet Reno’s keynote address

in February, the CGSR is meeting Lehman’s tough standards.

—Arnie Heller

Key Words: Center for Global Security Research (CGSR), Commission on Critical Infrastructure Protection, computer security, International Science and Technology Center (ISTC), Joint Verification Experiments (JVE), Lab-to-Lab program, land-mine removal, National Infrastructure Protection Center, nonproliferation, Threshold Test Ban Treaty (TTBT).

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About the Scientist



RONALD F. LEHMAN II is the Director of the Center for Global Security Research at Lawrence Livermore National Laboratory. He chairs the governing board of the International Science and Technology Center, an intergovernmental organization headquartered in Moscow, Russia. Lehman serves as Assistant to the Director of Lawrence Livermore and is a member of the Laboratory’s Institutional Review Board and Bio-Safety Board. He is a graduate of Claremont McKenna College (B.S., 1968) and earned his Ph.D. from Claremont Graduate School in 1975, the same year he went to Washington, D.C., as a fellow of the Hoover Institution at Stanford University to begin his long and substantive diplomatic career in international arms control, disarmament, and the nonproliferation of weapons of mass destruction. He has served three U.S. Presidents (Reagan, Bush, and Clinton), three Secretaries of State, three Secretaries of Defense, and three National Security Advisors in a variety of senior executive and advisory positions to promote peace through international disarmament and nonproliferation policymaking.

Shaped Charges Pierce the Toughest Targets

In early 1997, Lawrence Livermore successfully tested a shaped charge that penetrated 3.4 meters of high-strength armor steel. The largest diameter precision shaped charge ever built produced a jet of molybdenum that traveled several meters through the air before making its way through successive blocks of steel (Figure 1). A shaped charge, by design, focuses all of its energy on a single line, making it very accurate and controllable. When size is added to that accuracy, the effect can be dramatic. The success of this demonstration at the Nevada Test Site's Big Explosives Experimental Facility would not have been possible without the combination of reliable hydrodynamic codes and diagnostic tools that verify one another.

A shaped charge is a concave metal hemisphere or cone (known as a liner) backed by a high explosive, all in a steel or aluminum casing. When the high explosive is detonated, the metal liner is compressed and squeezed forward, forming a jet whose tip may travel as fast as 10 kilometers per second. Shaped charges were first developed after World War I to penetrate tanks and other armored equipment. Their most extensive use today is in the oil and gas industry where they open up the rock around drilled wells.

Leaving Trial and Error Behind

Early work on shaped charges showed that a range of alternative constructions, including modifying the angle of the liner or varying its thickness, would result in a faster and longer metal jet. These research and development efforts to maximize penetration capabilities were based largely on trial and error. It was not until the 1970s that modeling codes could predict with any accuracy how a shaped charge would behave. While the concept of a metal surface being squeezed forward may seem relatively straightforward, the physics of shaped charges is very complex and even today is not completely understood.

Today, a Livermore team headed by physicist Dennis Baum is continuing the development of shaped charges. Recent research has studied various aspects of their dynamics, including the collapse of the liner, jet formation, and jet evolution as well as the behavior of variously constructed liners. The team performs simulations using CALE (C-language-based Arbitrary Lagrangian-Eulerian), a two-dimensional hydrodynamic code developed at Livermore. When experimental results are compared to the simulations, the team has found that CALE accurately describes the mass



Figure 1. Testing personnel stand behind perforated blocks of armor steel after the early 1997 shaped-charge demonstration at the Nevada Test Site.

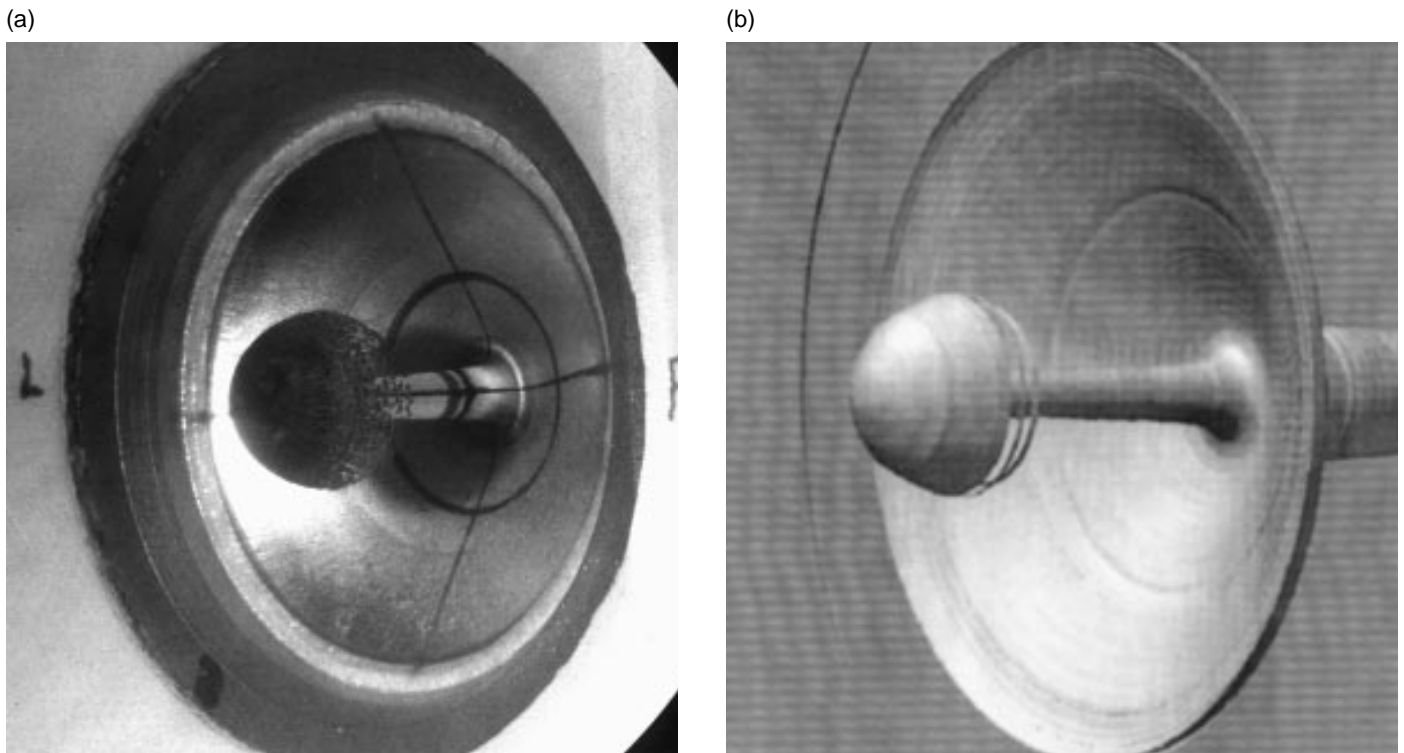


Figure 2. These images compare (a) actual experimental results with (b) the modeled simulation and demonstrate the validity of the modeling code. (a) An image-converter camera photograph of a conical, copper shaped charge known as a “Viper” taken at 19.3 microseconds after detonation. (b) The corresponding three-dimensional visualization of the results of the code simulation at the same time after detonation. The grid lines on the jet stem in (a) were drawn on the liner before detonation. After an experiment, researchers study photographs of the jet and use the lines to follow liner collapse and jet formation processes as a function of time.

and velocity distributions of the collapsing liner and resultant jet as a function of time. The code can also reproduce, albeit with less accuracy, various dynamic features of jet development such as the low-density shroud of material that streams back from the jet’s tip. This shroud is not uniform around its circumference, and its development is strongly affected by nonuniform distributions of the mass of the jet and other deviations from axial symmetry. The Livermore team uses ALE3D, a three-dimensional code still under development at the Laboratory, to more fully reproduce these details of jet behavior.

Figure 2 compares a computer simulation for an experiment in 1992 with the actual result. The simulation and the results varied by just 1 to 2%. Results from the experiment in early 1997 cited above were similar. With this ability to produce accurate simulations and thus rely on the codes, the team can go on to build similar shaped charges in different sizes for a number of national defense applications.

Diagnosing an Experiment

Livermore scientists use a variety of complementary diagnostic tools during experiments with shaped charges. X-radiography produces shadowgraphs that provide experienced researchers with information about the jet’s velocity, density, and mass distribution (Figure 3). The rotating-mirror framing camera, a kind of motion picture camera, can shoot millions of frames in a second. A typical shaped-charge jet-formation experiment lasts less than 30 microseconds, and the framing camera is usually set to record an image about once every microsecond. The exposure time for the framing camera may be anywhere from 100 to 200 nanoseconds, or billionths of a second.

The newest tool is the image-converter (IC) camera, which was developed at Livermore in the mid-1980s. A pulsed ruby laser is synchronized with the IC camera frames to provide illumination of the shaped charge. The electronic image tube that acts as the shutter for each image frame converts the

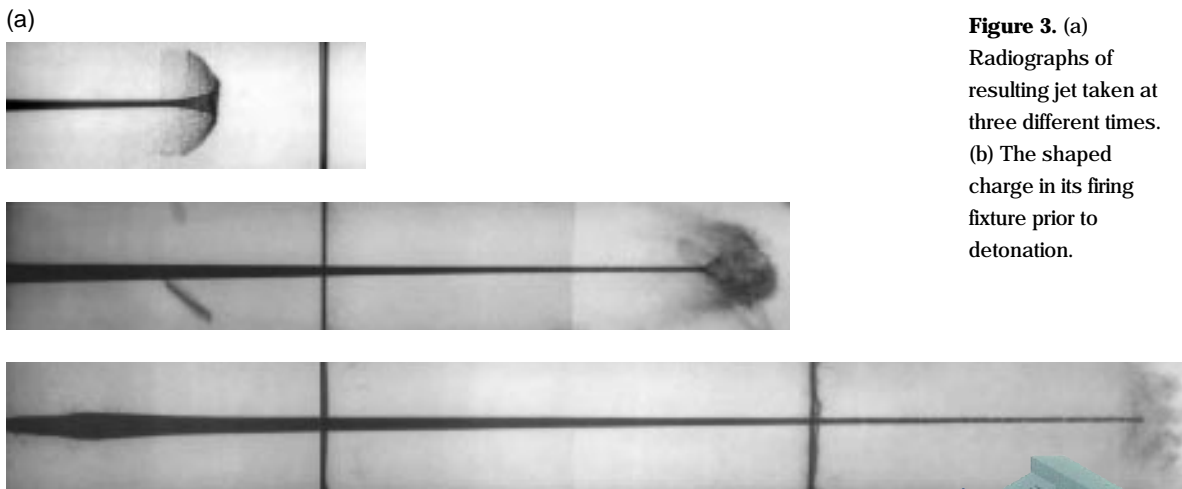


Figure 3. (a) Radiographs of resulting jet taken at three different times. (b) The shaped charge in its firing fixture prior to detonation.

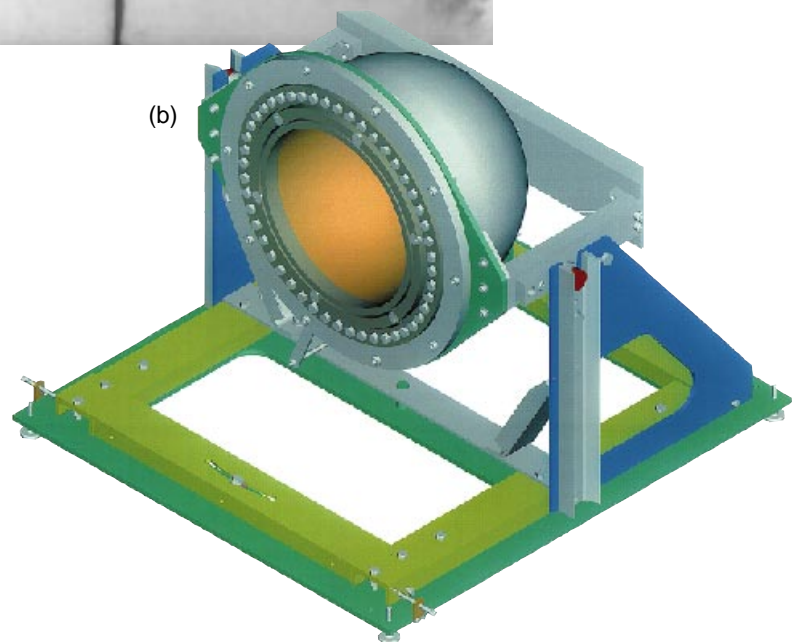
photons of laser light reflected by the shaped charge to photoelectrons. These photoelectrons are accelerated by a high-voltage pulse onto a phosphor, where they are reconverted to photons that are then transmitted to the film. With exposure times of just 15 to 20 nanoseconds (up to ten times shorter than those of the framing camera) and a band-pass filter mounted on the camera to exclude extraneous light, the IC camera has supplied the first truly high-resolution images of the formation and early flight of a shaped-charge jet. The image in [Figure 2\(a\)](#) was taken with an IC camera and shows fine-scale features, including instabilities near the tip, the breakup of the material in the head, and even small ripples in the stem. Without the pulsed ruby laser illumination and the band-pass filter of the IC camera, this photograph would show only the hot gases encasing the jet as an extremely bright, luminous sheath.

The IC camera can record single frames at eight different times, stereo pairs of frames at four different times for three-dimensional photography, or combinations of each. The various frames may be focused on different portions of the jet, or they may be set to produce sequential photographs of the same portion of the jet.

In the high-resolution photographs, individual features on the jet surfaces as small as about 100 micrometers can easily be detected and followed as they evolve over time. When this information is combined with data from framing-camera images and x-ray shadowgraphs, Livermore researchers have at their disposal a detailed, verifiable record of the evolution of the jet.

Meeting the Challenge

Baum's team has found that by modifying the shape and design of the liner, they can control tip velocity and the mass



distribution in the jet to maximize penetration of a target. But the problem, of course, is that with continual changes in materials and construction methods, targets become increasingly difficult to penetrate. Therein lies the never-ending challenge.

—Katie Walter

Key Words: ALE3D code, Big Explosives Experimental Facility (BEEF), C-language Arbitrary Lagrangian-Eulerian (CALE) code, framing camera, image-converter camera, Nevada Test Site, shaped charge, x-radiography.

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A New Approach for Magnetically Levitating Trains—and Rockets

FOR the past two decades, prototype magnetically levitated (maglev) trains cruising at up to 400 kilometers per hour have pointed the way to the future in rail transport. Their compelling advantages include high speeds, little friction except aerodynamic drag, low energy consumption, and negligible air and noise pollution.

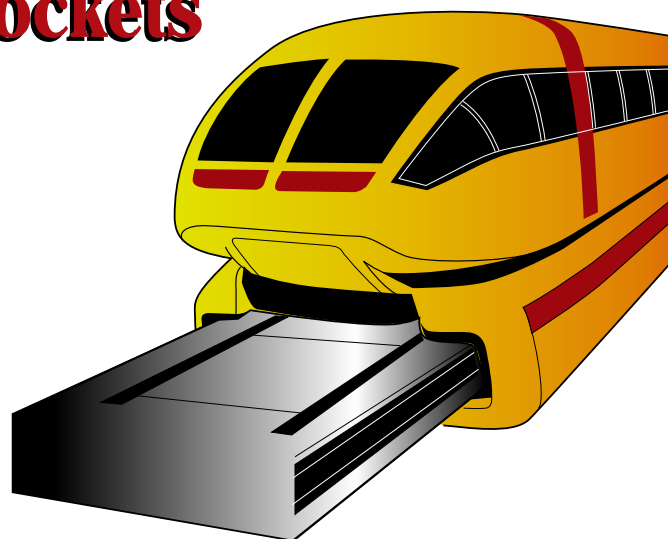
However, maglev trains also pose significant drawbacks in maintenance costs, mechanical and electronic complexity, and operational stability. Some maglev train cars, for example, employ superconducting coils to generate their magnetic field. These coils require expensive, cryogenic cooling systems. These maglev systems also require complicated feedback circuits to prevent disastrous instabilities in their high-speed operation.

Lawrence Livermore scientists have recently developed a new approach to magnetically levitating high-speed trains that is fundamentally much simpler in design and operation (requiring no superconducting coils or stability control circuits), potentially much less expensive, and more widely adaptable than other maglev systems. The new technology, called Inductrack, employs special arrays of permanent magnets that induce strong repulsive currents in a “track” made up of coils, pushing up on the cars and levitating them.

Totally Passive Technology

During the past two years, a Livermore team, headed by physicist Richard Post, has successfully demonstrated the Inductrack concept in test trials. The test runs demonstrated the system’s totally passive nature, meaning that achieving levitation requires no control currents to maintain stability, and no externally supplied currents flowing in the tracks. Instead, only the motion of train cars above the track is needed to achieve stable levitation. The results have been so promising that NASA has awarded a three-year contract to the team to explore the concept as a way to more efficiently launch satellites into orbit.

Inductrack involves two main components: a special array of permanent, room-temperature magnets mounted on the vehicle and a track embedded with close-packed coils of insulated copper wire. The permanent magnets are arranged in



configurations called Halbach arrays, named after Klaus Halbach, retired Lawrence Berkeley National Laboratory physicist. Originally conceived for particle accelerators, Halbach arrays concentrate the magnetic field on one side, while canceling it on the opposite side. When mounted on the bottom of a rail car, the arrays generate a magnetic field that induces currents in the track coils below the moving car, lifting the car by several centimeters and stably centering it.

When the train car is at rest (in a station), no levitation occurs, and the car is supported by auxiliary wheels. However, as soon as the train exceeds a transitional speed of 1 to 2 kilometers an hour (a slow walking speed), which is achieved by means of a low-energy auxiliary power source, the arrays induce sufficient currents in the track’s inductive coils to levitate the train.

To test the Inductrack concept, Post, project engineer J. Ray Smith, and mechanical technician Bill Kent assembled a one-twentieth-scale model of linear track 20 meters long (Figure 1). The track contained some 1,000 rectangular inductive wire coils, each about 15 centimeters wide. Each coil was shorted at its ends to form a closed circuit but not otherwise connected to any electrical source. Along the sides of the track, they attached aluminum rails on which a 22-kilogram test cart could ride until the levitation transition velocity was exceeded (Figure 2). Finally, the team secured Halbach



arrays of permanent magnet bars to the test cart's underside for levitation and on the cart's sides for lateral stability.

The cart was then launched mechanically at the beginning of the track at speeds exceeding 10 meters per second. High-speed still and video cameras revealed that the cart was consistently stable while levitated, flying over nearly the entire track length before settling to rest on its wheels near the end of the track.

Post says the test results are consistent with a complete theoretical analysis of the Inductrack concept he performed with Livermore physicist Dmitri Ryutov. The theory predicts levitation forces of up to 50 metric tons per square meter of magnet array using modern permanent magnet materials such as neodymium-iron-boron. The theory also shows levitation of loads approaching 50 times the weight of the magnets, important for reducing the cost relative to maglev vehicles.

External Power Needed

Post notes that a power source is needed to accelerate the cart to its operating speed of 10 to 12 meters per second. The first section of the test track uses a set of electrically energized track coils—aided by a stretched bungee cord—to reach this speed. A full-scale train might use an electronic drive system, as found on experimental German trains, or even a jet turbine,

as proposed by Inductrack engineer Smith. "Inductrack allows you the possibility of carrying all the power with you," emphasizes Post.

Even though the electromagnetic drag associated with Inductrack becomes small at high speeds, an auxiliary power source would also be needed to maintain the train's high speed against aerodynamic drag. The amount of power needed depends on the weight of the vehicle and its maximum speed. If the external drive power ever fails, or when the train arrives at a station, the train cars would simply coast to a stop, easing down on their auxiliary wheels. In this sense, Inductrack is a true fail-safe system.

Livermore is one of the few institutions to explore the uses of the Halbach array. Indeed, the Inductrack concept arose from Post's research on an electromechanical battery designed for superefficient cars and trucks (See [April 1996 S&TR](#), "A New Look at an Old Idea," pp. 12–19). The Livermore battery uses circular Halbach arrays both to generate power and to achieve nearly frictionless magnetic bearings that minimize the loss of stored energy.

Figure 1. The 20 meters of scale-model track containing inductive wire coils used to test the Inductrack concept at Livermore. The test cart and electric drive circuit are in the foreground.



Figure 2. The test cart in motion levitated above the test track. The Halbach arrays can be seen beneath the cart and suspended from its sides. These arrays generate a magnetic field that induces, from the motion of the car, currents in the coils contained in the track, lifting and centering the cart above the track.

“We just unrolled the circular magnetic arrays from the electromechanical battery into a linear array on the car that seemed ideal for trains and other vehicles,” he explains.

The Halbach array offers other benefits besides levitation. Because its magnetic fields cancel out above the magnets, there is no worry about magnetic fields affecting passengers’ heart pacemakers. In contrast, passengers must be magnetically shielded on maglev trains employing superconducting coils.

The consulting company of Booz–Allen & Hamilton conducted a preliminary feasibility study of Inductrack and compared it to other maglev technologies. The study found that while an Inductrack system would cost more to build than conventional rail systems, it should be less expensive than maglev trains using superconducting coils. The study also found that Inductrack should be able to achieve speeds of 350 kilometers per hour and up and demonstrate lower energy costs, wheel and rail wear, propulsion maintenance, and noise levels.

Launching Rockets

Last October, negotiations were completed on a three-year contract with NASA to build a new Inductrack model at Lawrence Livermore to demonstrate the concept at speeds up to Mach 0.5 (170 meters per second). NASA is interested in maglev technology to help launch rockets at sharply reduced costs. As conceived, a track would use a reusable launcher to propel a rocket up a ramp to almost Mach 1 speeds before the rocket’s main engines fire. According to Smith, the technology should be able to save about 30% of the weight of the launch vehicle. “Rocket engines are not fuel-efficient at low speed,” he points out.

The Livermore team is designing a 150-meter-long track, to be built at the Laboratory site, on which a scaled launch



cradle and rocket will be accelerated. Unlike the present track, the one for NASA will interleave powered drive coils with passive levitation coils to reach the required speeds. The team is partnered with computer scientists at Pennsylvania State University, who are developing an integrated design code that includes magnetics, aerodynamics, stresses, and control stability to assess full-scale systems.

Post believes Inductrack offers NASA the potential for a far less expensive technology for magnetic levitation launchers than approaches using superconducting coils. He and Smith note, however, that while the existing Inductrack model has demonstrated the principle of the concept, there are new issues to be addressed in launching rockets. Among these are high *g* forces, sustained speeds of Mach 0.5 or higher, the effects of fluctuating aerodynamic forces on the launching cradle and its payload, and aerodynamic and other issues associated with detachment and flight of rockets.

—Arnie Heller

Key Words: Halbach arrays, Inductrack, magnetically levitated (maglev) trains.

For further reading: Scott R. Gourley, “Track to the Future,” *Popular Mechanics* (May 1998), pp. 68–70.

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Each month in this space we report on the patents issued to and/or the awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Richard F. Post	Magnetic Levitation System for Moving Objects U.S. Patent 5,722,326 March 3, 1998	A means for magnetic levitation of high-speed objects such as trains. This system repels magnetic forces produced by the interaction of a flux-concentrated magnetic field (produced by permanent magnets or electromagnets) with an inductively loaded, closed electric circuit. Repelling magnetic forces, induced when magnets are moved with respect to another, are applied to magnetically levitate a moving object. Levitating power, drawn from motional energy of the train, represents only a few percent of the several megawatts of power required to overcome aerodynamic drag at high speeds.
Joseph P. Fitch Karla Hagans Robert Cough Dennis L. Matthews Abraham P. Lee Peter A. Krulevitch William J. Benett Luiz Da Silva Peter M. Celliers	Microminiaturized Minimally Invasive Intravascular Micromechanical Systems Powered and Controlled via Fiber-optic Cable U.S. Patent 5,722,989 March 3, 1998	A micromechanical system for medical procedures constructed in the basic form of a catheter with a distal end for insertion into and manipulation within a body and a near end with which a user controls the manipulation of the distal end. At the near end, a fiber-optic cable within the catheter couples external laser light energy to a microgripper at the distal end for gripping or releasing objects within the body. A converter receives laser light and mechanically actuates the microgripper.
Stephen E. Sampayan	Pulsed Hybrid Field Emitter U.S. Patent 5,723,954 March 3, 1998	A hybrid emitter that exploits the electric field created by a rapidly depoled ferroelectric material. Combining the emission properties of a planar, thin-film diamond emitter with a ferroelectric material alleviates problems associated with both types of emitters and provides a robust, long-lived, high-current-density cathode of the type required by emerging microwave power-generation, accelerator-technology, and display applications. This hybrid emitter is easy to fabricate, is not susceptible to common failures of conventional field emitters, and does not require specialized phosphors if used in flat-panel displays.
Detlev H. Tiszauer Lloyd A. Hackel	Speckle Averaging System for Laser Raster-Scan Image Projection U.S. Patent 5,729,374 March 17, 1998	A system that eliminates the effects of laser speckle from a laser projection system while preserving the depth of focus of the system and without introducing spurious viewing effects. The viewer's perception of speckle from a laser-generated image projection system is modified or eliminated by the addition of an optical deflection system (composed of one moving mirror and one stationary conical optic) that effectively presents a new speckle realization at each point on the viewing screen to each viewer for every scan across the field.
John F. Holzrichter Lawrence C. Ng	Speech Coding, Reconstruction and Recognition Using Acoustics and Electromagnetic Waves U.S. Patent 5,729,694 March 17, 1998	A complete mathematical coding of acoustic speech enabled by the use of electromagnetic radiation in conjunction with simultaneously recorded acoustic speech information. A feature vector is formed for each period of voiced, unvoiced, and combined voiced and unvoiced speech. The coding includes how to deconvolve the speech excitation function from the acoustic speech output to describe the transfer function of each time frame. Applications include speech coding, compression, synthesis, recognition, and translation.

(continued on page 24)

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Patents

Patent issued to	Patent title, number, and date of issue	Summary of disclosure
Robert F. Keville Daniel D. Dietrich	Miniature Piezo Electric Vacuum Inlet Valve U.S. Patent 5,730,417 March 24, 1998	A miniature piezoelectric, battery-operated vacuum inlet valve. The low-power (less than 1.5 watts), high-pulse-rate (less than 2 milliseconds) variable-flow inlet valve can be used for mass spectroscopy and other applications in which pulsed or continuous-flow conditions are needed. The valve is smaller than conventional piezoelectric valves by a factor of three and uses a 12-volt dc input/750-volt dc, 3-milliamphere output power supply.
Joe N. Lucas Tore Straume Kenneth T. Bogen	Identification of Random Nucleic Acid Sequence Aberrations Using Dual Capture Probes Which Hybridize to Different Chromosome Regions U.S. Patent 5,731,153 March 24, 1998	A method for detecting nucleic-acid sequence aberrations using a two-step immobilization process. Immobilization of a first hybridization probe is used to isolate a first set of nucleic acids in a sample that contains the first nucleic-acid sequence type. Immobilization of a second hybridization probe is then used to isolate a second set of nucleic acids from within the first set of nucleic acids, which contain the second nucleic-acid sequence type. The second set is then detected, its presence indicating the presence of a nucleic-acid sequence aberration.
Richard Pekala Lawrence W. Hrubesh	Compression Molding of Aerogel Microspheres U.S. Patent 5,731,360 March 24, 1998	An aerogel composite material produced by compression molding of aerogel microspheres (powders) mixed with a small percentage of polymer binder to form monolithic shapes. The mixture is placed in a mold, heated, and pressurized to a density of 50 to 800 kilograms per cubic meter. The resulting aerogels have cost-effective applications such as thermal insulation, filtration, inertial confinement targets, and double-layer capacitors.
Dennis O'Brien Robert L. Druce Gary W. Johnson George E. Vogtlin Troy W. Barbee, Jr. Ronald S. Lee	Method and System for Making Integrated Solid-State Fire-Sets and Detonators U.S. Patent 5,731,538 March 24, 1998	A microminiature slapper detonator comprising a solid-state, high-voltage capacitor, a low-jitter dielectric breakdown switch and trigger circuitry, a detonator transmission line, an exploding foil bridge, and a flier material. These components are fabricated using thin-film deposition techniques into a single, solid-state device that is safe, reliable, and inexpensive to manufacture.
Charles Vann	Laser Pulse Sampler U.S. Patent 5,732,172 March 24, 1998	A device for measuring the temporal shape of a laser pulse without the digital sampling and expensive components needed for measuring with a streak camera. The laser pulse directly illuminates a camera in the laser pulse sampler, making the sampler easier to calibrate and maintain because there is only one energy conversion—photons to electrons. The sampler's dynamic range is limited only by the range of its camera, which can be as high as 16 bits.

Reducing the Threat of Biological Weapons

Lawrence Livermore has taken a lead role in supporting DOE and DoD programs that are working to protect the nation in case of a biological attack. In just three years, Livermore expects to field continuously operating, fully automated biodetectors for rapid identification of biological agents and immediate reporting. In support of this identification process, Livermore's bioscientists are expanding the base of information about the DNA sequences of biological agents. Atmospheric models are being developed to study the fate and transport of biological agents in confined spaces and urban settings, and environmentally friendly decontamination methods are under development.

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At the Crossroads of Technology and Policy

Livermore's Center for Global Security Research (CGSR) was established in 1996 to bring the technology and policy communities closer together. Its goal is to reduce threats to international security—especially those associated with weapons of mass destruction—by sponsoring workshops, research fellows, and independent analyses. The Center joins Livermore scientists and engineers with academics, policymakers, military leaders, industry executives, and other technical experts to address issues involving national security technology and policy. Past topics have included chemical and biological weapons terrorism, nuclear materials smuggling, enhancing relations with Russian nuclear scientists, the future of nuclear forces, and environmental security. In February, the Center co-sponsored a workshop in which representatives from business, government, and technology addressed ways to protect the nation's banking, communication, computer, and power networks from a host of potential adversaries. Keynote speaker Attorney General Janet Reno announced the establishment of a new FBI center to investigate and prevent attacks on the nation's critical infrastructure and called for an unprecedented partnership with institutions like Lawrence Livermore.

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